Lake Nasser fisheries: Literature review and situation analysis

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LAKE NASSER FISHERIES: LITERATURE REVIEW AND SITUATION ANALYSIS

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LIST OF SYMBOLS AND ABBREVIATIONS

B	mean stock biomass
B_c	current average (annual) biomass, estimated current average biomass (according to the equation)
B_{MSY}	proportion of the unexploited biomass (B_o)
B_∞	maximum stock size
C	catch
E	rate of exploitation
f	index of effort
f_{MSY}	estimate of fishing effort corresponding to the estimate of maximum sustainable yield (related optimum effort)
F	fishing mortality
$F_{maxYPR'}$	fishing mortality rate to maximize yield per recruit
F_{MSY}	optimum fishing mortality rate
MEI	morphoedaphic index
q	catchability
T	total catch
Y_E	yield when the stock is in equilibrium
$Y_{c'}$	total current catch
Y_{MSY}	maximum sustainable yield
Y_∞	asymptotic yield
Z	total mortality rate

LIST OF ACRONYMS

CAPMAS	Central Agency for Public Mobilization and Statistics
CPUE	catch per unit effort
FMC	Fishery Management Center
GAFRD	General Authority for Fishery Resources Development
HDLDA	High Dam Lake Development Authority
NIOF	National Institute for Oceanography and Fisheries
MSY	maximum sustainable yield
YPR	yield per recruit

BACKGROUND

The following review draws heavily from the most recent reviews of Lake Nasser and its fisheries, including van Zwieten et al. (2011), Habib et al. (2014) and Habib (2015). It is supplemented with findings from the field study described in the final technical report, *Lake Nasser fisheries: Recommendations for management, including monitoring and stock assessment* (Halls 2015).

Aswan

Aswan Governorate lies in the south of Egypt close to the border with Sudan. The capital city of the governorate is Aswan, and it is divided into five districts: Aswan, Daraw, Kom Ombo, Nasr El Nuba and Edfu. According to the Central Agency for Public Mobilization and Statistics (CAPMAS), around 1.4 million people live in Aswan Governorate.

Most residents of Aswan rely on tourism as their main source of income. Aswan has been a world-famous tourist destination for at least a century, due to its history, its warm winter weather and its location as the gateway to Egypt's south. Aswan includes many visitor attractions, including the temples of Abu Simbel, Kalabsha, Philae, Kom Ombo and Edfu, in addition to the Nubia museum, the unfinished obelisk and the rock temples on the shore of Lake Nasser. There are also more modern tourist attractions, including the High Dam and Aswan botanical garden with its exotic tropical plants (www.aswan.gov.eg). Since the 2011 revolution, the tourist industry has collapsed, severely affecting the economy of the governorate and its people. Other sources of income in Aswan are agriculture and fisheries.

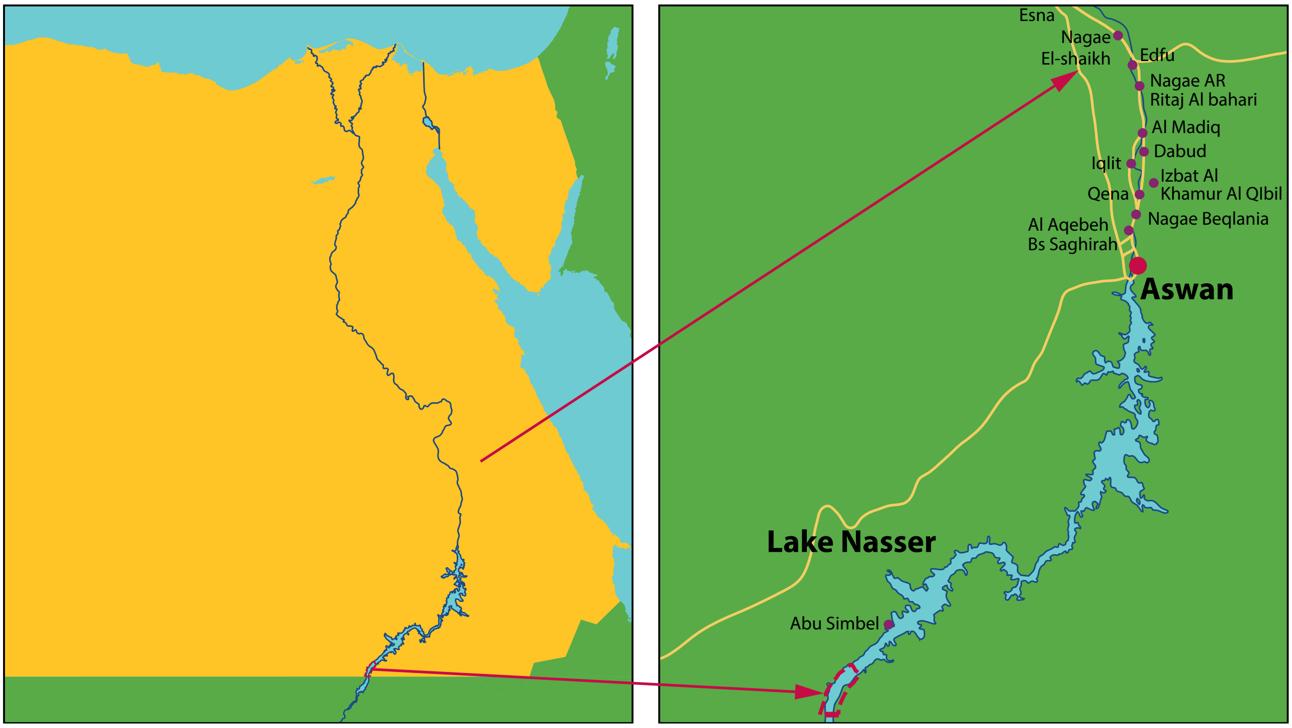


Figure 1. The location of Lake Nasser.

The Aswan High Dam Reservoir and Lake Nasser

The Aswan High Dam was constructed in the 1960s, creating the second-largest artificial lake (reservoir) in Africa, second only to Volta Lake in Ghana. The High Dam lies approximately 9 kilometers (km) south (i.e. upstream) of the old dam. The High Dam is a rock-fill dam made of granite and sand, with a vertical cut-off wall consisting of impermeable clay. It is 3600 meters (m) long, 980 m wide at the base, 40 m wide at the crest and 111 m tall. It contains 43 million m^3 of material. At maximum flow, 11,000 m^3 per second of water can pass through the dam. The reservoir behind the High Dam is 35 km wide at its widest point and extends about 480 km from the High Dam to the Dal Cataract in Sudan at the maximum storage level of 183 m above sea level. It covers a surface area of 5,237 km^2 at a 182-m water level and has a storage capacity of 150–165 km^3 of water (van Zwieten et al. 2011).

The dam is in a unique situation because it lies in a desert area where yearly rainfall is less than 4 millimeters and has a very high rate of evaporation of around 3 m per year (yr). Before the construction of the High Dam, Egypt suffered from alternate floods and droughts, depending on the season. This meant that farmers could grow only one crop per year after each year's flood. The dam was constructed to control flooding in the Nile River and store floodwater to release during the dry season. The construction of the dam also allowed the generation of electricity. The dam created a huge water body, Lake Nasser, named after President Nasser. The lake now provides an important source of fish for Aswan and the rest of Egypt (Habib et al. 2014). The air is very dry and the sky is almost completely cloudless. The only source of water is the River Nile with its inflow in the south. The outflow at Aswan is the continuation of the River Nile towards the north. This vast impoundment is in reality not a typical lake but rather an extremely slow-flowing river (Entz 1976). Important morphometric data of the reservoir is summarized in Table 1. The morphometric characteristics vary according to locality, being narrow and steep in some regions, while other parts are much wider and have low slopes (Habib et al. 2015).

The mean slope of the shoreline of Lake Nasser is steeper on the generally rocky or stony mountainous eastern shore than on the flatter, more open, wider, often-sandy western one.

The reservoir contains three regions: (i) the riverine southern part; (ii) the lacustrine northern part; and (iii) a region in between that has riverine conditions during the flood season and lacustrine characteristics in the remainder of the year. There are 85 dendritic inlets or side extensions of the reservoir, known as *khors*, which greatly increase the shoreline length (Figure 2; Table 2). Due to the prevalence of *khors*, the length of the eastern shoreline is almost double that of the western shoreline. The largest *khors* extend up to 55 km long at a lake water level of 180 m. These *khors* provide spawning and feeding habitat for fish and therefore are also important fishing areas. They are shallow and contain abundant phytoplankton. Water currents in the *khors* are limited and mostly affected by changes in lake water levels. There are clear annual fluctuations in water level, with the lowest recorded in the middle of July or August (van Zwieten et al. 2011; Habib et al. 2015).

Item	Water level (above sea level)	
	160 m	180 m
Length (km)	291.8	291.8
Mean width (km)	8.83	17.95
Surface area (km^2)	2.562	5.237
Mean depth (m)	20.5	25
Maximum depth (m)	110	130
Volume (km^3)	53	131
Shoreline (km)	5.416	7.875

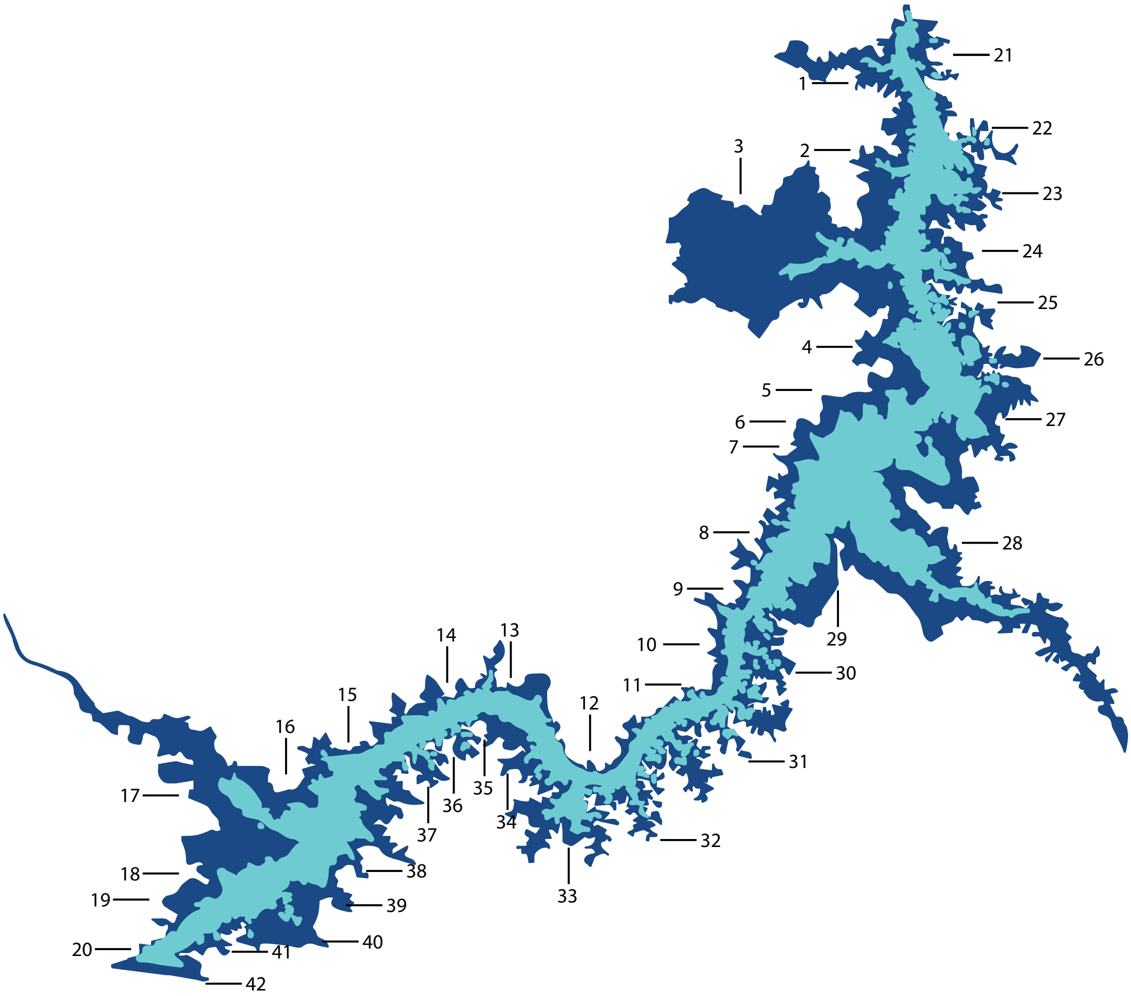
Source: Latif (1974).

Table 1. Morphometric data for Lake Nasser.

The Toshka Canal links the reservoir to the Toshka Depression. Floodwaters entered the depression in 1998 and then again in 2000, significantly expanding the original reservoir by 25%–30% and adding new fishing grounds.

Water-level fluctuations

Maximum water levels in Lake Nasser have varied from around 160 m to 180 m. During the past decade, maximum water levels have remained above 170 m, fluctuating by 1–2 m/yr (Figure 3). Water levels are distinguished into three categories: (i) dead water level (<150 m above mean sea level), which is the minimum level required for operating the hydroelectric power station of the High Dam; (ii) live water level (150–175 m); and (iii) flood-control water level (175–183 m). Further details on the hydrology, sedimentology and limnology of the lake are given in van Zweiten et al. (2011).



Lake Nasser

West

1. Khor El Ramla
2. Dihmit (West)
3. Khor Kalabsha
4. Mirwaw
5. Garf Hussein
6. Kushtamno
7. El-Daka
8. Kourta
9. Sayata
10. El-Madiq
11. El-Soboul
12. El-Malki
13. Thomas
14. Afla
15. Enaeba
16. Masmas
17. Khor Tushka (West)
18. Forkondl
19. Abu Simbel (West)
20. Sallano

East

21. Khor Manam
22. Dihmit (East)
23. Amberkab
24. Khor Rahma
25. Khor Ghazal
26. Khor Wadi Abyad
27. Khor Mariya
28. Khor El-Allaqi
29. El-Mehrraka
30. Khor El-Sabakha
31. Khor Wadi El-Arab
32. Khor Singari
33. Khor Korosko
34. Abu Handai
35. El-Dlwan
36. El-Derr
37. Genina
38. Tushka (East)
39. Armina
40. Abu Simbel (East)
41. Khor Or
42. Khor Adindan

Notes: The light blue color shows the extent of the reservoir in March 1988, the lowest water level on record was reached that year in July at 150.6 m above sea level. Dark blue represents the area flooded in November 1998 when the highest water level of 181.3 m (above sea level) was reached.
Source: Created based on images provided by the United States Geological Survey (www.usgs.gov).

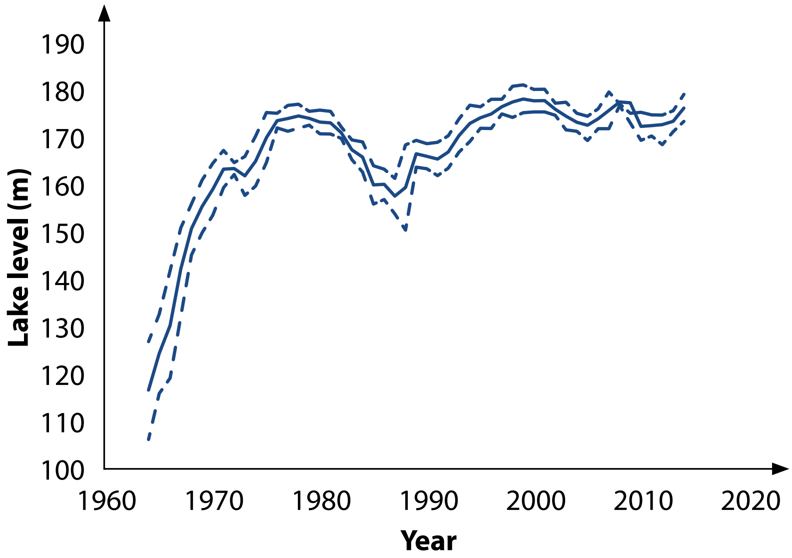
Figure 2. Location of ***khors*** and extent of minimum and maximum flood levels.
Source: van Zweiten et al (2011).

Regional variation in the lake environment

The southern region of the lake is more affected by flows from the Nile River than the northern region. Significant increases in turbidity occur in the southern part of the lake during the flood season (wet season). Nutrient-rich sediments support greater primary production in the southern region of the lake, where mean annual values of chlorophyll-a are estimated to be approximately 12 milligrams (mg)/m^3 compared to 8–11 mg/m^3 in the northern part of the lake. Secondary production, measured in terms of zooplankton concentrations and fish catch rates (catch per unit effort [CPUE]) are reported to exhibit similar north-south variation (Mohamed 1993b; Khalifa et al. 2000). Agaypi (1992) reported larger tilapia in the southern region of the lake compared to the northern. More rigorous statistical testing is required to confirm these regional variations in fish abundance.

Fish fauna

The known Lake Nasser fish community comprises 52 species from 15 families (Table 3). Major flora and other fauna present in the lake are described in van Zweiten et al. (2011).



Source: HDLDA.

Figure 3. Average (solid line) and minimum and maximum (broken lines) water levels in Lake Nasser, 1964–2014.

Serial	Name of *khor*		Characteristics at 180-m level		
		Length km	Surface area km^2	Perimeter km	Volume km^3
1	Wadi El Allaqi	54.83	490.8	510	11.57
2	Khor Kalabsha	47.20	620.0	517	7.16
3	Khor Masmas	33.35	266.8	127	4.41
4	Korosko	22.56	83.6	353	1.76
5	Rahma	23.58	95.2	232	2.15
6	El-Ramla (El–Birba)	25.72	101.2	284	0.96
7	Dihmit	20.50	56.8	226	1.71
8	Mariya	17.49	80.7	184	1.58
9	Wadi–Abyad	18.30	48.7	184	1.11
10	Shaturma	19.00	25.96	211	0.65
11	El Meharraka	8.70	99.25	53	0.81
12	Or	19.23	12.4	110	0.88
13	Tushka	15.02	66.9	117	1.44

Table 2. Dimensions of some Lake Nasser *khors*.

Family	**Species**
Cichlidae	*Tilapia zillii, Oreochromis aureus, Sarotherodon galilaeus, Oreochromis niloticus*
Latidae	*Lates niloticus*
Alestidae	*Alestes nurse, Alestes baremoze, Alestes dentex, Hydrocynus forskalii, Hydrocynus vittatus, Hydrocynus brevis*
Cyprinidae	*Barbus bynni, Labeo niloticus, Labeo coubie, Labeo horie, Labeo forskalii, Chelaethiops bibie, Barilius niloticus, Barilius loati, Discognathus vinciguerrae, Barbus werneri, Barbus prince, Barbus neglectus, Barbus anema*
Bagridae	*Bagrus bayad, Bagrus docmac*
Claroteidae	*Chrysichthys auratus, Chrysichthys rueppelli, Clarotes laticeps, Auchenoglanis biscutatus, Auchenoglanis occidentalis*
Clariidae	*Heterobranchus bidorsalis, Clarias gariepinus*
Schilbeidae	*Schilbe mystus, Schilbe uranoscopus*
Mochokidae	*Synodontis schall, Synodontis serratus, Synodontis batensoda, Synodontis membranaceous, Mochocus niloticus, Chiloglanis niloticus*
Mormyridae	*Mormyrops anguilloides, Mormyrus kannume, Mormyrus cashive, Petrocephalus bane, Hyperopisus bebe, Marcusenius isidori, Gnathonemus cyprinoides*
Citharinidae	*Citharinus citharus , Citharinus latus*
Distichodontidae	*Distichodus niloticus*
Tetraodontidae	*Tetraodon lineatus*
Protopteridae	*Protopterus aethiopicus*
Polypteridae	*Polypterus bichir*
Gymnarchidae	*Gymnarchus niloticus*
Malapteruridae	*Malapterurus electricus*

Notes: *Barbus prince* (This species is not found.)
Distichodus niloticus (This species is not found.)

Table 3. Fish species of Lake Nasser.

Descriptions of the fisheries

In 2005, the estimated commercial value of the fishery (including both fresh and salted fish) was around USD 17 million (Béné et al. 2008).

Target species and bycatch

More than 50 species of fish were identified in Lake Nasser during the first few years after its establishment. Since then, the ecosystem has undergone change, and species diversity has declined. Some species are now restricted to the southern part of the lake, while others have vanished altogether. Historically, species of tilapia (*Oreochomis niloticus, Sarotherodon galilaeus, Tilapia zillii* and *Oreochromis aureus)* have formed the bulk of the catch, comprising as much as 80% of the total catch by weight, followed by Nile perch (*Lates niloticus*), tigerfish (*Alestes* and *Hydrocynus* spp.) and *Labeo* species.

Fishing gears

Three main kinds of fishing gear are used in the lake: bottom gill nets (*kobok*), floating gill nets (sakarota) and trammel nets (*duk*). Bottom gill nets (*kobok*) are used on a semi permanent basis. They are usually set in the *khors* but sometimes in open waters, depending on the location of the fishing camp. They are raised every second night or sometimes every night. The fishing location is changed about once every 14 days. The number of nets joined together is sometimes as high as 20 or as low as 3. The average number of nets used is about 10. The nets may be up to 10–15 m deep. Their mesh size ranges from 10 to 20 centimeters (cm). The fish caught in these nets are *L. niloticus* (Nile perch, *samoos*); *O. niloticus* (*bolti*); *Labeo* spp. (*lebis*); *Barbus bynni* (*benni*) and *Clarias* spp. (*karmout*).

In the past, floating gill nets (*sakarota*) were used only in the southern part of the lake with mesh sizes from 3 to 6 cm, but recently they have been used in both the northern and southern parts of the lake with mesh sizes from 2 to 3 cm. Their length varies from 20 to 50 m and their depth varies from 4 to 5 m. The number of nets varies from 20 to 40 for a boat. Sometimes 100 m of nets are joined together to form a single net, particularly during the flood season. Fishing occurs every night, and the catch is gutted and salted. The predominant fish caught in gill nets are *Alestes* spp. (*raya*) and *Hydrocynus* spp. (*kalb el samak*).

Trammel nets (*duk*) are used to catch *bolti*, *samoos*, *bayad* and *karmout* that have attained sufficient size. Most of the catch is delivered fresh. The net length is about 20 m and 1.2–1.5 m deep. The outside walls have a mesh size of 30–40 cm and inside walls of 8–9 cm. The trammel net is piled up at the rear of the boat and is easily handled by one person; while another person rows the boat, the net is cast and set off against the rocky faces of the shoreline a few meters away from the shore. The boat then moves in between the shore and the net. The fisher, using a long pole, hits the surface of the water. The fishers also drum on the boat deck with their feet, sending vibrations into the water. The fish are scared into the nets and get entangled. In summer, the fishing commences after dark and continues until just before dawn, while in winter fishing starts in the early morning and continues until about 1 hour after sunset. It is confined to shallow water. This fishery is the main support for the supply of fresh fish to the governorate, to nearby governorates and to the wholesale market in Cairo.

Long-line fishing is done to a limited extent in the lake. The long lines are commonly used in deep water to catch Nile perch (*samoos*) and *bayad* in the summer season. Fry and fingerlings of *bolti* (*O. niloticus*) and *lebis* (*Labeo forskalii*) are used as bait.

Trammel nets are reported to have a higher catch rate compared to floating gill nets (Habib 2015).

Fishing operations

No fishers are permanently settled around the lake. Most come from rural areas of Sohag and Qena governorates. Living conditions are poor, without facilities such as potable water supplies or sanitation. The catch is landed to temporary camps set up on the shore or small islands. Carrier boats purchase the catch 2–3 times per week and supply the camps with food, fuel, nets and ice. Fresh fish storage is in basic containers with a small amount of ice, so it must be collected within a few days. Salted fish is prepared and packed into containers that do not need to be collected as often, as the salting process preserves the fish (Habib et al. 2014).

Fishing vessels

The majority of boats are not owned by fishers but rather by private owners or businesses. There are 3264 fishing boats currently in operation, most of which are wooden; some are motorized. Flat-bottomed boats are mostly employed in the northern half of the lake for trammel net fishing, while round-bottomed boats are used for floating gill net fishing in the southern part of the lake. Both are operated by crews of two or three people.

Fishing effort

Approximately 13,000 fishers operating 3000 fishing boats are affiliated with the cooperatives (Table 4). However, the precise number of fishers operating in the lake is unknown. The number of fishers was estimated to be approximately 3000 in 1993 and 5000 in 1999. According to the General Authority for Fishery Resources Development (GAFRD 2015), the estimated current number of fishers operating on the lake is 14,230 (Habib et al. 2014).

Fisheries organizations and fishing rights

Lake Nasser is divided into fishing zones allocated to particular fishing organizations and companies under a series of decrees. According to Decree Number 621 issued in 1981 and Decree Number 45 issued in 1985, the lake is divided between one company and four fisheries cooperative societies (Table 5; Figure 4).

The following six investment companies are also allocated rights in the lake: (i) the Egyptian Fish Marketing Company; (ii) HU Group Company; (iii) Misr-Kuwait Company; (iv) Misr Aswan Company for Fishing and Fish Processing; (v) Investor Association and Small Manufacturing; and (vi) Grand Lake Company (van Zwieten et al. 2011).

The fishing cooperatives have fishing rights to an area occupying about 60% of the total reservoir surface. The investment companies have fishing rights over the remaining area, of which 34% cover deep-water areas and the remaining 6% cover enclosures.

According to these decrees, the cooperative societies have rights to allocate fishing areas to their members and are responsible for supervising fishing activities. Fishers may only apply or re-apply for a fishing boat license if the application to the management authority (GAFRD) is accompanied by a letter confirming membership in a cooperative.

Each cooperative society operates carrier boats (Table 6) to collect catches from fishers and supply them with food, fuel, ice and equipment. The cooperative societies also appear to allocate access rights for fishers to fish within their zones.

Fish disposal

More than 150 carrier boats collect fish from groups of fishers on a regular basis and land to Aswan, Garf Hussein or Abu Simbel harbors. The carrier boat fleet operates over the whole lake. The fish-holding capacity of these boats ranges from 3 to 65 metric tons (t). Refrigerated trucks are also used to collect fish. Many stakeholders claimed that, by law, fish may only be landed at these official harbors, where it is weighed by the High Dam Lake Development Authority (HDLDA). These claims are questionable, because no legislation to this effect exists.

Carrier boat owners are required to pay harbor fees upon landing (EGP 250/t) for harbor services and to cover management administration fees. Licenses to transport fish by road, valid for 12 hours only, are also issued by the management authority at the harbors.

Name of cooperative society or company	Number of fishing boats	Number or fishers
Misr Aswan Company	218	780
Aswan Sons Cooperative Society	615	2,300
Fishermen Cooperative Society (Mother)	1,632	7,880
Nubian Cooperative Society	520	2,230
El-Takamol Cooperative Society	61	260
Total	**3,046**	**13,450**

Source: GAFRD (2015).

Table 4. Number of fishers and number of boats affiliated with each of the fishing cooperative societies.

Zone	Location	Shoreline (km)	Exploitation rights
1	High Dam to Dihmit	187	Misr Aswan Company for Fishing and Fish Processing
2	Dahmeet to Dihmit	300	Aswan Sons Cooperative
3	Mirwaw to Ebrrim	800	Fishermen Cooperative Society (known as the Mother Cooperative)
4	Ebrrim to the Egyptian border	370	Nubian Cooperative Association for Fishing
5	Khor Or on the east side of the reservoir to the Egyptian border	66	El-Takamol Cooperative for Fishing

Source: van Zweiten et al. (2011).

Table 5. Lake Nasser fishing zones.

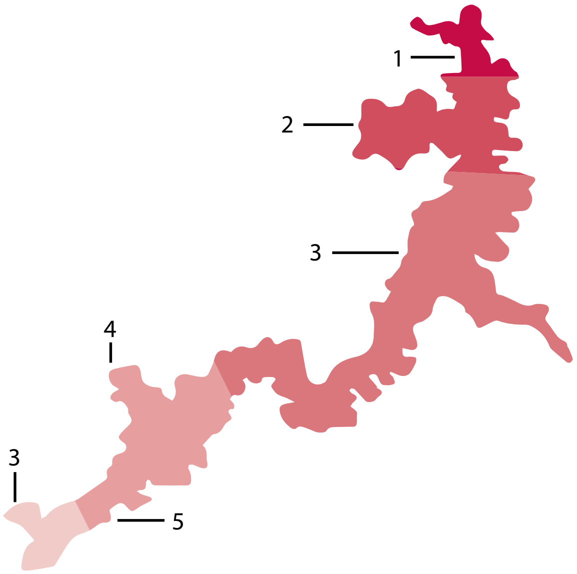
Preservation starts on the reservoir by cooling with crushed ice in insulated boxes of 10–30 kg capacity. The boxes are stored in refrigerating stores belonging to two companies: Misr Aswan Company for Fishing and Fish Processing and the Egyptian Company for Fish Marketing. Large tilapia and Nile perch are filleted, while small ones are cooled and transported to local markets in Aswan and nearby governorates (van Zwieten et al. 2011).

Landings of fresh fish transported from the lake were shared between two companies: the Egyptian Fish Marketing Company and Misr Aswan Company for Fishing and Fish Processing. They own processing plants, cold stores, trucks and even several retail shops in Cairo and Alexandria. In addition to providing marketing services, they produce tilapia and Nile perch fillets (van Zwieten et al. 2011). The two companies are responsible for processing, freezing, packing and transporting fish to market.

Lake Nasser was the only lake in Egypt that was subject to compulsory pricing of fish, which began in 1979 according to several declarations (decrees) of the Minister of Food Supply. Compulsory tilapia prices were as low as EGP 0.17/kg in 1979 and rose to EGP 2.6/kg in 1999.

On 14 June 2001 the Prime Minister issued several decrees to end the monopoly of the marketing companies and open the door to private marketing companies. Upon liberation of the fish trade, fish prices varied according to size grades for each species.

Now more than 20 fish traders purchase fish from the main harbors. Fishers are also permitted to sell their catch on the open market.



1. Misr Aswan Company (187 km shoreline)
2. Aswan Sons Cooperative Society (300 km shoreline)
3. Fishermen Cooperative Society (Mother) (800 km shoreline)
4. Nubian Cooperative Society (370 km shoreline)
5. El-Takamol Cooperative Society (370 km shoreline)

Source: High Dam Lake Development Authority (HDLDA)

Figure 4. Distribution of fishing areas in Lake Nasser.

Cooperative or company	Carrier boats
Misr Aswan Company	3
Aswan Sons Cooperative	25
Mother Cooperative	84
Nubian Cooperative	33
El-Takamol Cooperative	4

Table 6. Number of carrier boats operated by the fishing cooperatives, 2013.

Aswan tilapia sold in Obour market (Cairo) is mostly large-sized tilapia (more than 1 kg each). Aswan tilapia is sold in Obour market at prices lower than the landing price of tilapia in Aswan. However, the quality of Aswan tilapia in Obour market is very poor compared to the quality of the same fish for sale in Aswan fish markets. This indicates that there may be a significant unregistered trade in tilapia, allowing fish to reach the market at lower prices and with poor quality.

Salted fish

Salting fish is a traditional method of preservation. The main species of salted fish are tigerfish and *Alestes*: *Hydrocynus forskalii* (*Kalb el samak*), *Alestes nurse* (*sardina*), *Alestes dentex* (*raya*) and *Alestes taremoze* (*raya*). Processing begins by first exposing fish to direct sun for about 24 hours. Large-sized fish are then gutted before being salted, while small fish are salted whole. The fish are rubbed with salt. Salt is also placed in the abdominal cavity of gutted fish and is sprinkled on the fish. These fish are then packed into containers (plastic barrels or metal tins), and a thick layer of salt is placed on top of the fish. The containers are transported to salted fish storage facilities where fish are separated by species and size and packed into separate tins for sale.

Supporting services and infrastructure

There are harbors at Aswan, Garf Hussein and Abu Simbel to receive fish landings. Boat building and repair services are available in Aswan and Abu Simbel. These boatyards have good facilities and skills suitable for the building, repair and rebuilding of wooden fishing vessels but have little capacity for building new fiberglass or metal vessels. Facilities for repair and maintenance of inboard and outboard engines are available in Aswan and Abu Simbel.

The HDLDA constructed several facilities to support the fisheries sector, including the following:

- a fisheries research vessel;
- a fish research station at Abu Simbel;
- a floating dock for repairing fishing boats;
- ice plants at each harbor;
- fish processing factories and freezers at Aswan and Abu Simbel;
- a mill to produce aquaculture feeds from waste fish;
- three fish hatcheries at Sahary, Garf Hussein and Abu Simbel;
- two fry trucks for transportation of fry and fingerlings;
- a technical school for fishing and fish rearing.

Fisheries dynamics (spatial and temporal patterns)

Fish landings have been reported since 1966 but their accuracy has been questioned because of the prevalence of unreported landings (van Zwieten et al. 2011). As the reservoir slowly filled, fish landings from Lake Nasser increased from 751 t in 1966 to a peak of 34,200 t in 1981 (Figure 5). Since then, recorded landings have shown large fluctuations, but with a downward trend.

This decline in landings has been explained as the result of the imposition by the authorities of a fixed price for fresh fish, which spurred the development of a large black market. As a result, fish is smuggled outside the regular fish-marketing system and falls outside the official landing statistics. The sharp drop in the estimated fish landings in about 2000 has been attributed mainly to this black market (Béné et al. 2008).

Moreover, consumption by fishers, avoidance of taxation, poaching, and discards owing to spoilage or catch below the minimum legal size combine so that a large proportion of the catch is unreported. Khalifa et al. (2000) speculated that recorded harbor landings were about 50% of the total catch.

In spite of these claims, there are no reliable estimates of unreported catch or changes in their proportion over time as a result of changes to policies or market arrangements. Moreover, significant variations in fishing effort and possibly lake level are also likely to have contributed to these catch variations.

Spatial and temporal variation in catch composition

Historically, *Oreochromis niloticus* made up the bulk of catch (70%), *Sarotherodon galilaeus* contributed about 20% and *Lates niloticus* made up about 6%. *Tilapia zillii* and *Oreochromis* *aureus* were also recorded to be present in the lake but at low levels, with *T. zillii* contributing only around 2% of the total catch. However, *S. galilaeus, T. zillii* and *O. aureus* are now relatively more common in the catch (see below), while species of *Alestes*, cyprinids and catfish are also landed in commercial quantities.

The proportion of cyprinids and catfishes decreased rapidly in the first decade after impoundment but increased in later years. At the start of the fishery, 50% of the fish was sold salted. This proportion gradually decreased to only 4% but has increased again. Van Zweiten et al. (2011) describe temporal variation in catch composition to 2004 in more detail. The species composition of the catch has not been recorded since 2004 and therefore changes since then cannot be determined. However, consultations with stakeholders during May 2015 suggest that the abundance of *O. niloticus* has declined significantly, whereas the smaller species, *S. galilaeus*, *T. zillii* and *O. aureus,* have increased in relative abundance. Species belonging to *Alestes* and *Hydrocynus* genera are also reported to now be more abundant.

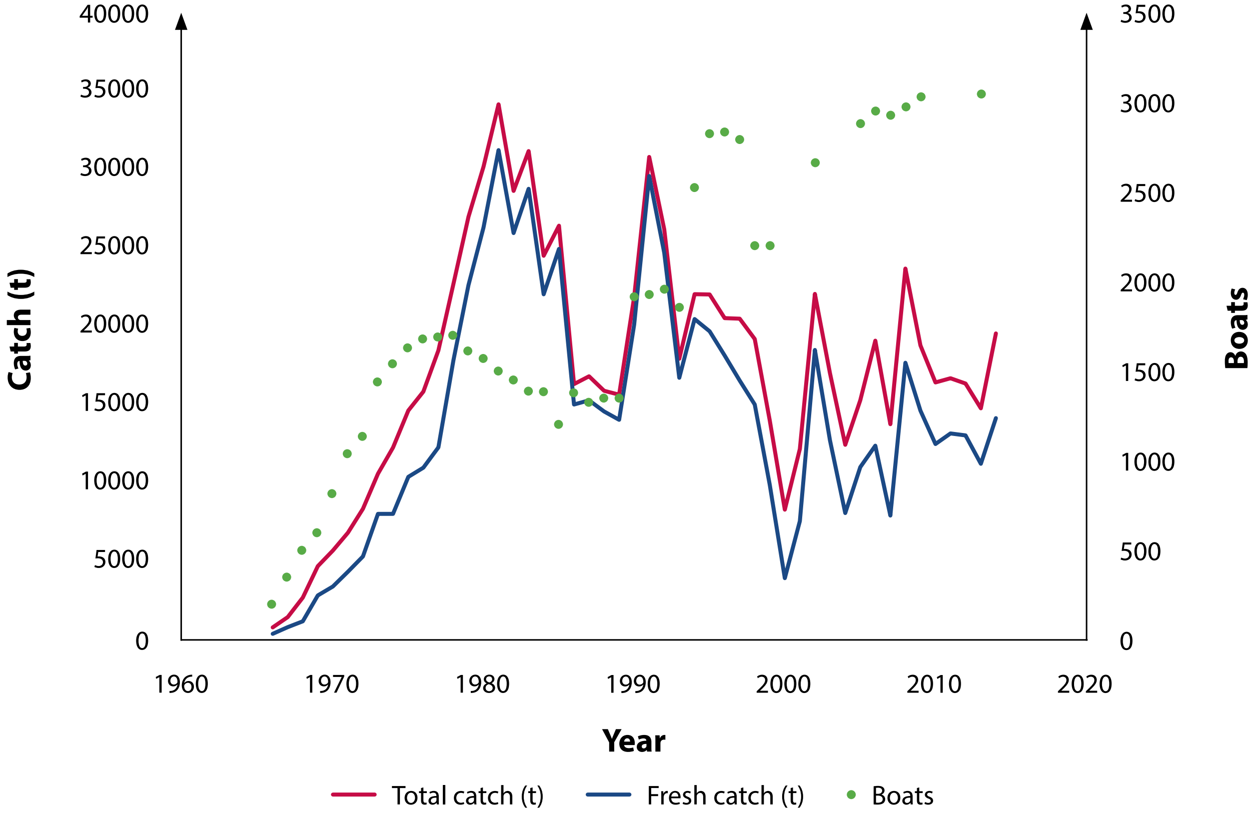
Khalifa et al. (2000) reported no differences in catch composition between the northern and southern regions of the lake.

Trends in fishing effort

Fishing effort rose rapidly to about 1800 boats by the late 1970s as the reservoir filled and the fishery developed (Figure 5). During the next decade, the number of vessels fell steadily to around 1300 by 1985. Thereafter, the number of boats has risen to more than 3000 in recent years. Van Zweiten et al. (2011) describe changes to the number of fishers up to 2004.

Spatial and temporal variation in catch and catch rates

Mohamed (1993a; 1993b; 1993c; 1993d) examined spatial variations in catch rates between 79 locations in the lake. Mean catch rates were found to be higher (by a factor of 1.7–1.9) in the southern part of the lake compared with the northern part. A significant difference in mean monthly catch rates (p<0.001) was found following re-analysis of the survey data during May 2015 (Figure 6).



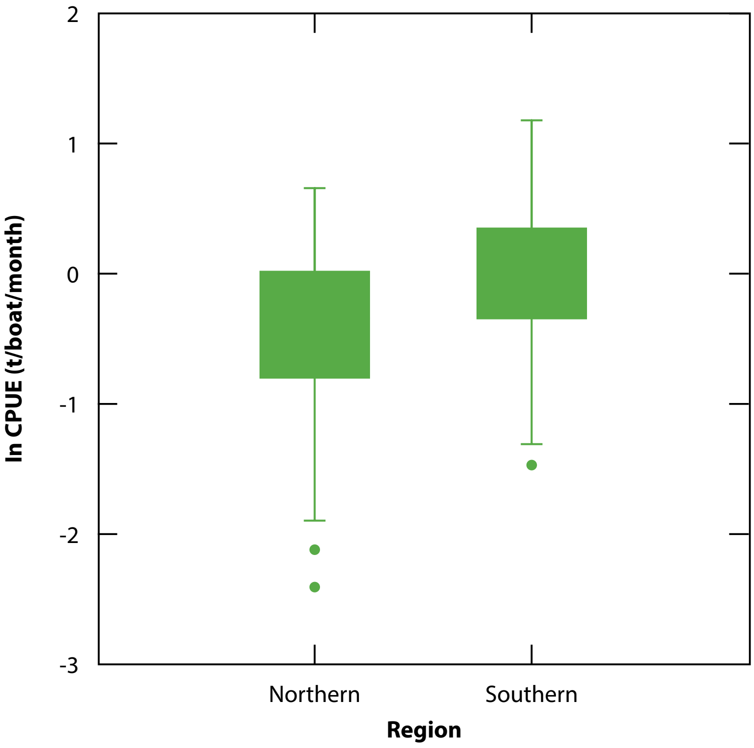
Landings of salted fish are indicated by the difference between the total catch and the catch of fresh fish. Salted fish are expressed as fresh weight animal equivalents. The number of licensed boats each year is also shown. Data source: HDLDA (unpublished) landing data.

Figure 5. Estimates of fish catch from Lake Nasser, 1970–2013.

Catch rates peak between February and April, coinciding with the spawning period for *O. niloticus*. A closed season, from the middle of April to the middle of May, was implemented until 2011 to protect these spawning aggregations following recommendations made by the Fishery Management Center (FMC). (See page 20)

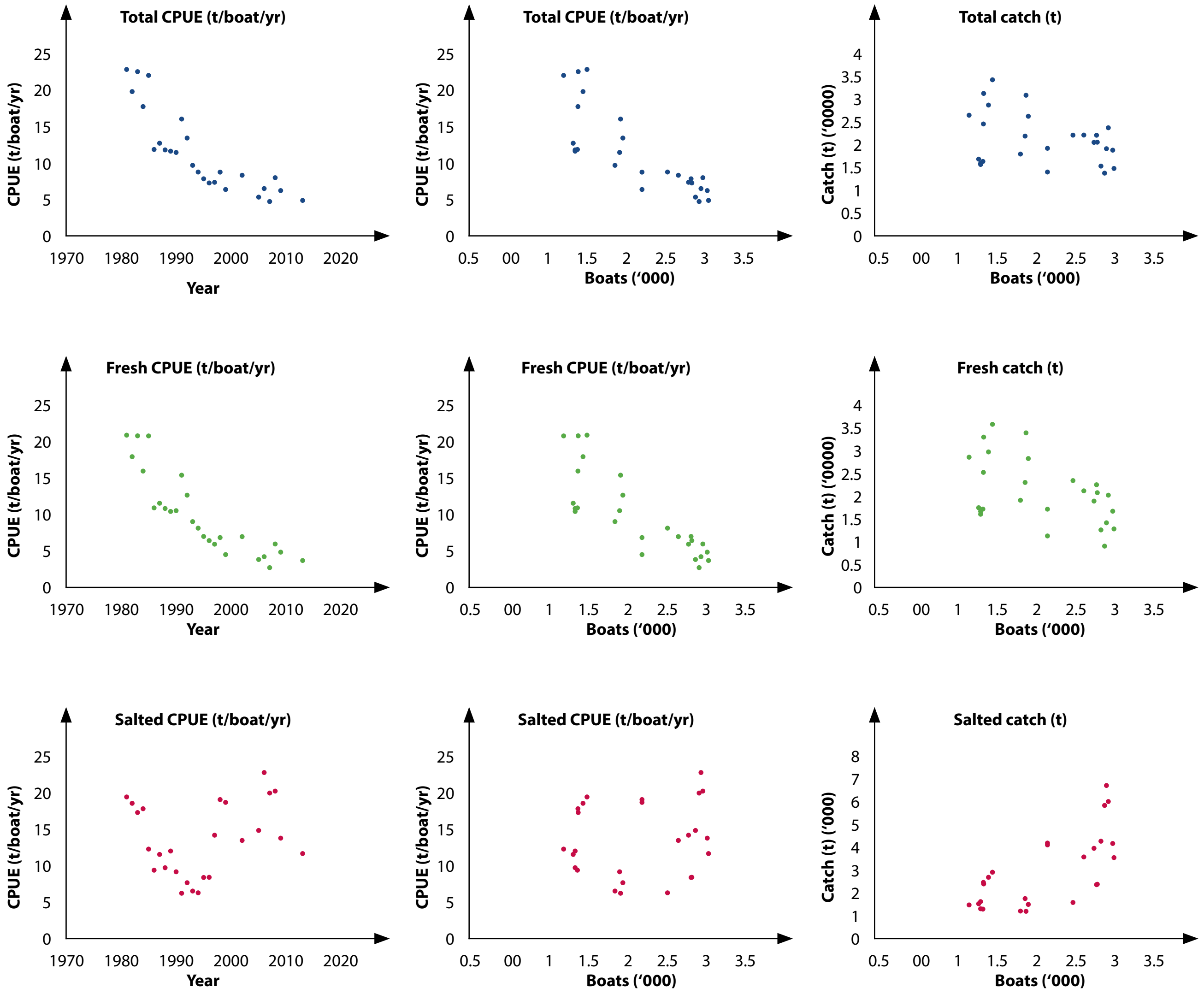
Catch rate (CPUE) trends

Long-term trends in CPUE (catches per boat) show that CPUE increased from 1966 as the reservoir filled and the fish populations grew, in spite of rapidly increasing fishing effort, until it peaked around 1980, when the carrying capacity of the lake may have been reached. After 1981, CPUE has fluctuated with—for fresh and total catch combined—a clear downward trend corresponding to increasing fishing effort (number of boats; Figure 7). This significant stock depletion effect for fresh fish (and total fish) is evident for salted fish only until 1994, after which no trend is discernible.



Data source: Bishai et al. (2000).

Figure 6. Log_e-transformed monthly catch rates recorded in the southern and northern sectors of Lake Nasser, 1990–1991.



Data source: Unpublished data, HDLDA.

Figure 7. Trends in catch rates for the major categories of fish in Lake Nasser, 1981–2014.

Key management institutions and stakeholders

Descriptions of the key management stakeholders and institutions and their respective roles and responsibilities are poorly documented in the literature. The General Authority for Fishery Resources Development (GAFRD) is the main management authority for the lake's fish resources and is responsible for monitoring and controlling the fishery, including the issuing of fishing licenses. The High Dam Lake Development Authority (HDLDA) was the former management authority. Responsibility for the management of the lake's resources was transferred from the HDLDA to GAFRD in May 2010. The Fishery Management Center (FMC) of the HDLDA is responsible for research and providing scientific advice, but currently has no capacity in these fields. The National Institute for Oceanography and Fisheries (NIOF) also provides scientific advice with respect to fisheries but has limited capacity in Aswan. Fishing companies and cooperatives allocate access rights to the fishery and grant fishers permission to apply for a boat license to fish in their designated zones. They also provide supporting services to fishers and purchase their catch.

The main stakeholders include the following:

- Ministry of Agriculture and Land Reclamation;
- HDLDA;
- FMC;
- GAFRD;
- NIOF;
- Aswan Governorate;
- fishing cooperatives and companies;
- investment companies;
- Cooperative Union for Aquatic Resources;
- Misr Aswan Company for Fishing and Fish Processing;
- Egyptian Fish Marketing Company;
- traders;
- fishers;
- those engaged in supporting sectors.

The exact nature of the institutional arrangements between these stakeholders appears highly complex and far from transparent. Comprehensive stakeholder and institutional analyses remain outstanding and will need to be undertaken before changes to the existing management system can be proposed. This should include a detailed description of their management roles and responsibilities.

Management capacity

Management capacity is not examined in the literature. Relevant comments with respect to stakeholder capacity are made in the final technical report (Halls 2015).

Fisheries policy

According to van Zweiten et al. (2011), fisheries policy in Egypt and for Lake Nasser seeks to accomplish the following:

- Increase fish production.
- Increase the contribution of Lake Nasser fisheries to the gross domestic product.
- Provide employment, particularly for young people.
- Improve the incomes and the standard of living of local fishers and their families.
- Achieve more rational and sustainable use of the natural resources of the reservoir.

Fisheries legislation and other obligations

A review of fisheries legislation and other obligations remains outstanding. This must be completed before changes to the existing management system can be proposed.

Management goals and operational objectives for each fishery

The literature review did not reveal any specific goals and objectives for the lake's fisheries. Indeed, it remains uncertain if such objectives have been formally agreed and documented. No references to specific goals or objectives, or to relevant documentation, were made by the stakeholders consulted during the study, including the current management authority (GAFRD). An appropriate and effective management system for the lake cannot be designed or implemented until these goals and objectives are explicitly defined, approved by relevant stakeholders and documented.

Fishery indicators and reference points

It appears that catch is the main indicator of management performance. No attempts are made to monitor other important indicators such as fishing mortality, *F*, or spawning stock biomass. Boat licenses or the number of active boats can provide an index of effort, *f*, but these appear poorly recorded judging by existing gaps in the records. Furthermore, while reference points, including Y_{MSY}, f_{MSY} and F_{maxYPR}, have been estimated for some species, as well as the aggregated multispecies assemblage, it appears they have not been formally employed as a reference to monitor management performance or to control harvesting.

Harvest strategies and decision-control rules

While a formal harvesting strategy for the lake's resources has not been explicitly documented, it would appear that a size-based harvesting strategy is employed based upon minimum mesh- and fish-size landing rules. It is assumed that this strategy seeks to prevent growth overfishing (when fish are harvested at an average size that is smaller than the size that would produce the maximum yield per recruit). It may also seek to prevent recruitment overfishing (the rate of fishing above which recruitment to the exploitable stock becomes significantly reduced) by ensuring that fish can spawn before becoming vulnerable to the fishery. A closed season aims to further protect the spawning stock during spawning aggregations.

Unfortunately, it appears that no control rules have been set for the fishery. This probably reflects the paucity of relevant fishery indicators and reference points selected to monitor management performance and progress towards the achievement of specific objectives for the fishery.

Management strategy and measures

The following technical measures were proposed by the FMC:

Input controls (fishing effort restrictions)
There are no regulations that limit fishing effort on the lake, including the number of licensed boats.

Output controls (catch limits)
There are no rules or regulations to control the amount of catch from the lake.

Technical measures (size limits, closed seasons and closed areas)
Under Law #124, Issued 1983, the Ministry of Agriculture has the right to do the following:

- Set minimum gear-size and fish-landing sizes.
- Restrict the capture of certain species of fish.
- Close areas to fishing.
- Control which fishing gears may be used.
- Determine fish license type and number permitted in each zone.

The FMC recommended the following measures. Note that these are not included in fisheries legislation and therefore cannot be enforced by law:

- **A closed season between 15 April and 15 May.** This was introduced in 1991 to reduce the capture of mature fish (spawners), particularly tilapia, during the spawning season. This closure has not been effectively enforced since 2011. Attempts were made to assess the effectiveness of the closed season on catch rates, but these were unsuccessful (Habib 2015). Van Zweiten et al. (2011) question the value of this closed season without evidence of its effectiveness.

- **A closed area in *khor* Kalabsha.** This area was stocked with tilapia fingerlings.

- **A minimum mesh size of 12 cm for bottom gill nets and trammel nets.** The aim was to prevent fishers catching small tilapia (less than 25 cm in length or body weight of less than 500 grams) to maintain the reproductive capacity of the stock and to prevent recruitment overfishing. These size restrictions appear to have been formulated on the basis of a yield-per-recruit (YPR) analysis described by Mekkawy (1998) but this cannot be confirmed.

Stock enhancement

Following the construction of hatcheries by the HDLDA, stocking of 150 million Nile tilapia fingerlings was to take place since 1988 in four locations: Aswan, Garf Hussein, Abu Simbel and Tushka. Habib (2015) reports that the FMC released Nile tilapia fingerlings in the south part of the *khor* Kalabsha every year from 1988 to 1993 in varying numbers. A robust statistical assessment of the impacts of this stock enhancement is required.

Aquaculture

The FMC researched two types of fish culture technology: net cages and fish enclosures.

Net cage culture was used on an experimental basis to test the performance of the filter-feeding exotic species silver carp (*Hypophthalmichthys molitrix*) in the open water of the main channel of Lake Nasser, which is rich in natural food (phytoplankton). Artificial propagation of silver carp and mass production of fingerlings was carried out at the FMC in Aswan. The FMC succeeded in applying a culture system for silver carp without artificial feeding. The main target of the experiment was to study the effect of stocking density on the growth rate of silver carp in net cages and the best location to allocate the net cages. In spite of this research, silver carp were not stocked into the lake because of concerns that it could disrupt ecosystem functioning and because market demand was weak.

Fish enclosures were developed to increase fish production without any loss of storage water from the lake. Enclosures are formed by netting off the entrances of *khors* from the main lake.

Photo Credit: Ahmed Nasr-Allah/WorldFish

Salted fish in cans, Aswan.

The first enclosure was constructed in 1979 by Misr Aswan Company inside *khor* El Ramla with a total area of 5000 *feddans* (2100 hectares). Ten small nurseries were also constructed, with areas ranging between 5 and 10 *feddans* (2.1 to 4.2 hectares). Broodstock Nile tilapia were added at a stocking ratio of 2 females to 1 male to increase the number of fry. An integrated system was used with Nile tilapia and ducks reared in the enclosure to utilize the duck manure as fertilizer to increase natural food availability (phytoplankton and zooplankton) for fish. When the water level of Lake Nasser decreased during May or June, the nets were lifted and all the fish were released into the main enclosure. Fish production at *khor* El Ramla was 130 t through 1979–1980 before fish enclosures were constructed but rose to 1134 t after the enclosure was built in 1981–1982. In 2004, a tender procedure took place for investment companies to submit their technical and security plans to enhance fish production in their sectors. Six companies were selected and allocated 16 enclosures with a total area of 62,000 *feddans* (26,000 hectares).

Fish production from the enclosures of the investment companies in Lake Nasser during 2005–2008 is shown in Table 7. These estimates of production from the enclosures are subject to bias because they include production from outside the enclosure.

Van Zweiten et al. (2011) describe other stock enhancement activities that have been explored by the lake authorities.

Management plans

No official plans have been formulated to manage the fish resources of Lake Nasser.

Monitoring and evaluation activities

See page 23.

Stock assessment activities

See pages 24–34.

Company	Enclosure	Total area (feddans)	Fish production (t)					
			2005	2006	2007	2008	2009	2010
The Egyptian Fish Marketing Company	El Shenyara	22,000	387	705	393	630	306	32
HU Group Company	Khor Rahma Marwaw East Khor Soliman	5,829	0	37	25	74	-	-
Misr Kuwait Company	Allaqi Khor El Sokar	9,636	81	126	111	179	94	10
Misr Aswan Company for Fishing and Fish Processing	Khor Shalabia Khor Sengary Khor El Seboa Khor Krosko	2,059	7	86	63	73	-	-
Investor Association and Small Manufacturing	Khor Kata Khor Gattas	1,982	78	591	249	399	1,289	73
Grand lake Company	Khor El Batikha Khor Armna Khor Tushka	10,528	47	1,404	505	942	648	204
Total			**600**	**2,949**	**1,346**	**2,297**	**2,337**	**319**

Source: HDLDA.

Table 7. Fish production estimates from fish enclosures.

MONITORING PROGRAMS AND SURVEYS

Routine catch assessment surveys and frame surveys

No catch assessment or frame surveys have been undertaken on the lake. Carrier boat landings and supplies of fish transported by road to the three main harbors are weighed and enumerated by the management authority. Carrier boat records of fish weights purchased from each fisher are used to check the total landed weight. Carrier boat records also provide an estimate of the number of active vessels. Any fish not passing through the three main harbors will be unreported in the catch statistics. Until 2004, catch was recorded by species. Thereafter it has been recorded as either fresh or salted. A vessel license register is maintained. Any unlicensed vessels will not be included in the reported effort statistics (number of boats).

Ad hoc surveys

Khalifa et al. (2000) sampled catch by species and effort by gear type from fishers landing at the major *khors* of Lake Nasser from 1996 to 1997. Catches of *Oreochromis niloticus* and *Sarotherodon galilaeus* were also sampled for length and weight. *Khors* were sampled from four sampling strata: (i) *khors* El Ramla, Dahmit and Kalabsha; (ii) *khors* Abesco, El Allaqi and Garf Hussein; (iii) *khors* Korosko, El Seboa, Wadi El Arab and Tomas; and (iv) *khors* Aniba, Tushka and Forgondi. At least one *khor* in each sector was sampled during the survey. Indices of abundance (catch per boat per day and catch per fisher per day) were estimated and length frequency data was analyzed using standard procedures.

Hydro-acoustic surveys

Several *ad hoc* hydro-acoustic surveys have been undertaken in specific locations on the lake during 1982, March 2006, February and July 2007, and March 2009. The surveys appeared not to have been systematic, appeared to have limited coverage of the lake, and indicated low fish densities (Habib 2015). Discussions held with former FMC staff revealed that these surveys were unsuccessful and uninformative and were therefore discontinued.

Photo Credit: Ahmed Nasr-Allah/WorldFish

Fish boxes at harbor, Aswan.

DATA AND PARAMETER ESTIMATES

Catch and effort data

Time series of catch and effort data have been compiled from the HDLDA (Annex 1). Where missing, effort data (number of boats) was estimated by linear interpolation.

While this is believed to be the most reliable data, considerable uncertainty surrounds the accuracy of this data and therefore the stock assessments upon which it is based. Discussions held with stakeholders suggest that undocumented adjustments to estimates of catch have been made in the past to account for under-reporting and unrecorded landings, particularly during the past 15 years. To complicate matters further, GAFRD and the HDLDA appear to collect and report (and possibly adjust) their own data sets. Improving the rigor of basic catch and effort data collection and reporting procedures will therefore be fundamental to improving the management of the lake's resources.

Population and fishery parameters

Growth and natural mortality

Khalifa et al. (2000) and Adam (2004) estimated von Bertalanffy growth model parameters for the tilapia species *Oreochromis niloticus* and *Sarotherodon galilaeus* from the analysis of length frequency data (Table 8). Parameters of published weight-length relationships are given in Table 9. Life history parameters for other economically important species in the lake are given in Table 17 of van Zweiten et al. (2011).

Habib (2015) compared growth rates of tilapia between 1970 and 1990 and concluded that growth rates declined during this period. This decline was most pronounced in the northern compared to the southern part of the lake. Food categories of major fish species in Lake Nasser are given in Table 10.

Fishing mortality

The annual instantaneous fishing mortality rate, F, has not been estimated for any species in the lake for over a decade (Table 11). These estimates from Khalifa et al. (2000) and Adam (2004) suggest that even a decade ago, the most important species of tilapia were overexploited ($E>0.5$).

Time series of estimates of the total mortality rate Z for *O. niloticus* and *S. galileaus* for the period 1966–1994 given in Bishai et al. (2000, 338) indicate significant increases in fishing mortality (F). During this period, Z has increased for these species from approximately 0.5 to 0.8/yr, and 0.3 to 0.9/yr, respectively.

Catchability, *q*

Mekkawy (1998) estimated q for the tilapia fishery by fitting a generalized stock production model (Fox 1975) to the catch-effort time series for *O. niloticus* and *S. galilaeus*. (See Table 162 of Bishai et al. [2000].)

Selectivity

Selection curves for trammel nets for tilapia species (*Oreochromis niloticus* and *Sarotherodon galilaeus*) are described by Adam (1992a; 1992b; 1993). (See page 328 of Bishai et al. [2000].)

Species	L_∞ (cm)	K (yr^{-1})	t_0 (y)	M (yr^{-1})	References
Oreochromis niloticus	54.7	0.27	-0.75	0.24	Khalifa et al. (2000)
		0.17–0.48			Habib (2015)
	76.38	0.0875	-0.93		Mekkawy et al. (1994)
	52	0.275	0.75		Agaypi (1992)
Sarotherodon galilaeus	37.8	0.29	1.20		Khalifa et al. (2000)
		0.36			Habib (2015)
	42	0.12	4.17	0.36	Adam (2004)

Table 8. Estimates of von Bertalanffy growth function parameters for species inhabiting Lake Nasser.

Stock-recruitment relationships

Mekkawy (1998) described stock re-recruitment relationships for *Oreochromis niloticus* and *Sarotherodon galilaeus* derived from virtual population analysis. Model fits and parameter estimates are given on pages 374–76 of Bishai et al. (2000).

Potential yield estimates

Lake Nasser is reported to have been in a eutrophic state since 1978 (Bishai et al. 2000). During the past three decades, several researchers have estimated the potential yield of fish from Lake Nasser (Table 12). Estimates of potential yield have ranged from 11,000 t/yr to 46,000 t/yr, but all are subject to potential bias resulting from equilibrium assumptions, violation of regression model assumptions, failure to account for the effects of fishing effort, or model assumptions.

Ryder and Henderson (1975) estimated the potential yield on the basis of morphoedaphic index (MEI) as lying between 16,000 and 19,000 t using a modified version of the model for tropical lakes (Gulland 1971; Regier et al. 1971). However, the MEI is considered to be a poor predictor of potential yield (Crul 1992).

Habib and Aruga (1987) estimated potential yield of tilapia to range from approximately 23,000 t to 46,000 t based upon estimated rates of primary production in the lake and trophic conversion efficiency rates of tilapia. The midpoint (34,500 t) corresponds to the estimated maximum yield recorded in 1981 (Habib et al. 2014). The estimation method assumed that tilapia occupy approximately 10% of the lake area and approximately 10% of tilapia production is exploited by the fishery.

JICA (1989) estimated the potential yield (asymptotic yield, Y_∞) of the lake by fitting a logistic curve to estimates of annual catch. Potential yield was estimated to be approximately $0.5Y_\infty$ (40,000–45,000 t/yr). This method assumes equilibrium conditions (i.e. observed catches are sustainable), and no account was taken of fishing effort corresponding to the catch observations.

Vanden-Bossche and Bernacecek (1991) quoted other estimates, notably by Sadek (1984), who suggested a potential yield of 30,000 t (equivalent to 67 kg/ha/yr), and Entz (1984), who estimated potential yield at 35,000 t (equivalent to 78 kg/ha/yr).

Yamaguchi et al. (1990) developed a statistical (multiple linear regression) model to predict fish yield using shoreline length in previous years as explanatory variables but no account was given to variation in fishing effort. Van Zweiten et al. (2011) dismissed the validity of this model.

Species	*a*	*B*	References
Oreochromis niloticus	5.88844E-05	2.94	Adam (1996)
	0.02402702	2.97	Abdel-Azim (1974)
	0.03190803	2.87	Abdel-Azim (1974)
	0.02045973	3.02	Abdel-Azim (1974)
	0.00165	2.6	Agaypi (1992)
	5.8304E-05	2.94	Adam (1994)
	0.02466	2.93	Mekkawy et al. (1994)
	0.0736	2.84	SECSF (1996)
Sarotherodon galilaeus	0.016221836	3.12	Abdel-Azim (1974)
	0.00165	2.6	Agaypi (1992)
	0.000161102	2.78	Adam (1994)
	0.03145	2.9	Mekkawy et al. (1994)
	0.002534	2.5	SECSF (1996)

Table 9. Estimates of length-weight relationships ($W=aL^b$).

	Phytoplanktivores			Zooplanktivores	Bethivores			Piscivores		
	Peri-phyton	**Diatoms**	**Filamentous algae**	**Zooplankton**	**Mollusks**	**Nematodes and annelids**	**Insect larvae**	**Shrimp**	**Crab**	**Fish**
Lates niloticus							X	X	X	X
Bagrus docmac						X	X	X		X
Hydrocynus forskahlii							X	X		X
Synodontis spp					X	X	X			
Schilbe mystus					X		X	X		X
Mormyridae						X	X			
Labeo spp					X	X	X			
Alestes nurse, A. baremoze				X						
Oreochromis niloticus, Sarotherodon galilaeus	X									
Chrysichtys auratus, Chrysichthys rueppelli		X	X			X	X	X		

Source: van Zweiten et al. (2011).

Table 10. Food categories of major fish species in Lake Nasser.

Species	Reference	L (cm)	K	t (years)	Z	M	F	T/L (years/ cm)	L (cm)	E=F/Z	Phi prime	Reference	Phi prime	Resilience	Population doubling time (years)	Vulnerability to extinction
L. nibticus	1	180	0.069	0.79	0.35	0.17	0.18	0.74	18	0.5	3.35	3	3.76	Medium	5.4	Very high (67.8)
T.zillii	1	26.49	0.325	2.346	1.37	0.79	0.58	1.47	17.6	0.4	2.36	3	2.74	Medium	1.6	Low, moderate (30.61)
A. dentex	1	40.022	0.322	1.205	0.8	0.7	0.1	1.35	20.3	0.1	2.71	3	2.68	Medium	2.68	Moderate (36.63)
O. niloticus	1	50.39	0.16	2.569	0.73	0.42	0.31	0.9	21.45	0.4	2.61					
O. niloticus	2	54.73	0.27	-0.745	1.21	0.24	0.97	na	19	0.8	2.91	3	3.06	Medium	1.6	Moderate (35.42)
S. galilaeus	1	42.75	0.12	4.17	0.83	0.36	0.47	0.8	19	0.6	2.34					
S. galilaeus	2	37.8	0.294	-1.187	1.97	0.34	1.63	na	17	0.8	2.62	3	2.66	Medium	1.6	Low, moderate (30.24)

Source: van Zweiten et al. (2011).

Table 11. Estimates of fishing mortality (***F***) and rates of exploitation (***E***) derived from growth parameter estimates and length-converted catch curves.

According to the FMC, the total annual potential fish catch in the lake is between 24,000 t (at a water level of 164 m above sea level) and 30,000 t (at a water level of 172 m above sea level; Habib et al. 2014). It is understood that this estimate is derived from historical observations of catch. The method therefore assumes that the catch observations were at equilibrium (sustainable). No attempt was made to account for the effects of fishing effort.

Estimates of target and limit reference points (MSY, F_{MSY}, $F_{0.1}$, etc.)

Mekkawy (1998) described the linear response of catch (biomass) to fishing effort measured in terms of boats for *O. niloticus* and *S. galilaeus*. Fishing effort explained approximately 30%–40% of the variation in fish catch. Mekkawy (1998) estimated the average maximum sustainable yield (MSY) by different methods described below.

Photo Credit: Ashley Halls/WorldFish

Fish trader loading fish at one of the Aswan High Dam landing sites, Lake Nasser, Aswan.

Maximum sustainable yield (Y_{MSY}) – Cadima estimator

Mekkawy (1998) used the method of Cadima (Garcia et al. 1989) to estimate maximum sustainable yield (Y_{MSY}) for *O. niloticus* and *S. galilaeus*. The model is often applied to developing or developed fisheries where catch and effort time series are not yet available, but biomass estimates are occasionally obtained from, for instance, trawl or acoustic surveys. Cadima's model is a generalized version of Gulland's potential yield estimator for exploited fish stocks for which only limited stock assessment data is available:

$$Y_{MSY} = 0.5ZB_C$$

where B_c is the current average (annual) biomass and Z is the total mortality rate. Since $Z = F + M$ and $Y_c = FB_c$, the author suggested that in the absence of data on Z, the equation could be rewritten as

$$Y_{MSY} = 0.5(Y_C + MB_C)$$

where Y_c, is the total current catch and B_c is the estimated current average biomass.

Using Cadima's model, Bishai et al. (2000) present estimates of MSY for *O. niloticus*, *S. galilaeus* and *L. niloticus* by year in their Table 152. Estimates of MSY in 1992 for these three species were approximately 61,000 t, 26,100 t and 7000 t respectively. Combined, the MSY would be in the order of 94,000 t.

Garcia et al. (1989) show that Cadima's model gives unbiased estimates only when the stock is unfished or happens to be fished at MSY at the time of the survey for biomass estimates. At any other level of exploitation, Cadima's estimator will be biased if it is assumed that the stock responds according to a surplus production model. The model tends to overestimate MSY when $F < M$ and underestimate MSY when $F > M$ and does not provide an estimate of the fishing effort or mortality to achieve MSY.

Fishing mortality to maximize YPR (e.g. F_{maxYPR} or $F_{0.1}$)

Mekkawy (1998) estimated the annual instantaneous fishing mortality rate to maximize YPR (e.g. F_{maxYPR}) and to B_{MSY} as a proportion of the unexploited biomass (B_0) for both *O. niloticus* and *S. galilaeus*, corresponding to an age at first capture ranging between 1 and 3 years, length at first capture, and net-mesh size (Bishai et al. 2000, 396–98). The results suggest that YPR would be maximized under the patterns of exploitation shown in Table 13.

Unfortunately, the author did not attempt to estimate limit reference points to avoid recruitment overfishing (e.g. $F_{20\%SPR}$) and therefore no account of the sustainability of these fishing strategies was taken.

YPR analyses assume that recruitment will remain constant. In practice, one of the greatest sources of uncertainty in fisheries management is the very high variability in the recruitment of fish to the stock. Including a stock-recruitment relationship in an analytical YPR changes its predictions dramatically. While YPR often rises asymptotically with increasing F, (as was found by Mekkawy [1998] for *O. niloticus* for a $t_c = 3$ years), a YPR model including a stock-recruitment relationship behaves more like a surplus production model. (See Hoggarth et al. [2006], 49).

Surplus production model estimates

Mekkawy (1998) fitted Schaefer's surplus production model to catch and effort data for individual *khors* using data for different periods of the available time series to estimate Y_{MSY} for the multispecies assemblage (per month per fishing area). Summing estimates across the *khors*, the MSY of the lake was estimated to be approximately 59,700 t. Data for three *khor* fishing areas was omitted from the analysis since no decline in CPUE with effort was observed in these areas.

The approach used to fit the models unrealistically assumes that the observed catches represent equilibrium values—i.e. that observed catches are sustainable at the observed fishing efforts. Alternative biomass dynamics models do not make these equilibrium assumptions.

Mekkawy (1998) also fitted a power function to the complete time series of catch and effort data (1966–1992):

$$\text{Catch } (C) = 0.148928\, f^{\,1.5975378}$$

Fishery or resource	Potential yield (t/yr)	Method	References	Comments
Multispecies assemblage	24,000–30,000	Observations of historic catch by the FMC	Habib et al. (2014)	Equilibrium assumptions (observed catch in year *y* is sustainable). No account of fishing effort.
Multispecies assemblage	?	Statistical (regression) model with shoreline length as explanatory (and dependent) variable	Yamaguchi et al. (1996)	The regression model predicts catch as a function of shoreline length (not potential yield) but regression model assumptions are violated and model result is theoretically unexpected. No account is taken of changes in fishing effort.
Multispecies assemblage	30,000–35,000	Sadek (1984); Entz (1984)	Vanden-Bossche and Bernacscek (1991)	
Multispecies assemblage	40,000–45,000	Logistic curve fitted to catch estimates; potential yield estimated to be approximately $0.5Y_\infty$	JICA (1989)	Equilibrium assumptions. No account of fishing effort. Unconventional model.
Tilapia	23,000–46,000	Primary production and trophic model	Habib and Aruga (1987)	Key model parameter estimates (e.g. trophic conversion efficiencies and habitat areas, etc.) require supporting evidence (references).
Multispecies assemblage	16,000–19,000	MEI (Regier et al. 1971)	Ryder and Henderson (1975)	Equilibrium assumptions. No account of fishing effort. MEI models not considered reliable or robust.

Table 12. Summary of potential yield estimates for Lake Nasser.

Species	YPR_{max} (kg/recruit)	F_{maxYPR} (yr^{-1})	Age at first capture, t_c (years)	Length at first capture, l_c (cm)	Mesh size (cm)
O. niloticus	0.025	32	3	22.2	11.52
S. galilaeus	0.17	0.15	2.5	15.6	7.7

Table 13. Selected results of the YPR analysis of Mekkawy (1998).

The power function model has no maximum, and therefore, MSY and the corresponding fishing effort F_{MSY} cannot be determined.

Mekkawy (1998) observed increasing CPUE with effort during the period of initial lake formation (1966–1972). This may reflect the rapid growth of fish populations in response to the increasing carrying capacity of the lake as the reservoir filled and nutrient levels rose. A similar phenomenon was observed in response to the introduction of Nile perch to Lake Victoria in East Africa. Here the perch population grew to the lake's carrying capacity approximately 30 years after its introduction.

Mekkawy (1998) also fitted other models to different periods of the catch and effort time series for the multispecies assemblage, including a hyperbolic form with no maximum catch value. Separate Schaefer models were also fitted to the two main species of tilapia and the multispecies assemblage using data for the period 1973–1992. Y_{MSY} for the entire lake assemblage was estimated to be approximately 62,000 t/yr (Table 14). Estimates of fishing effort (f_{MSY}) corresponding to the estimates of Y_{MSY} vary from 1300 to about 9000 boats.

Mekkawy (1998) also fitted a Graham curve to the catch-effort time series for *O. niloticus* and *S. galilaeus*:

$$Y_E / B = k - (k / B_\infty)*B$$

where Y_E is the yield when the stock is in equilibrium, B is the mean stock biomass, B_∞ is the maximum stock size and k is constant. The estimate of Y_{MSY} for the two tilapia species combined was approximately 54,000 t (Table 14). Since the average tilapiine catch of the years 1991–1992 represented 93.5% of the total catch, the Y_{MSY} for the entire lake assemblage was estimated to be approximately 58,000 t (Mekkawy 1998).

To address the equilibrium assumptions of the methods described above, Mekkawy (1998) also fitted a generalized stock production model (Fox 1975) to the catch-effort time series for *O. niloticus* and *S. galilaeus*. As well as estimates of MSY and f_{MSY} (Table 14), this exercise also generated estimates of catchability (q) for the tilapia fisheries. (See Table 162 of Bishai et al. [2000].) Catchability gives the proportion of the stock removed by one unit of fishing effort. For the last model year examined (1991 and 1992), q ranged from 0.00035 to 0.00043. These values are approximately twice as high as those estimated using the available data compiled for this report.

Accounting for variable lake area

To account for variation in the size of the lake, Mekkawy (1998) fitted a Schaefer model to the catch-effort observations with an additional term ($A_{(i)}$) describing the average area of the lake during the preceding 6-year period to the catch rate observation in year i:

$$Y_{(i)} / f_{(i)} * A_{(i)} = a + bf_{(i)}$$

This version of the model estimated an MSY of approximately 57,500 t corresponding to 1313 boats. This estimate of optimal effort is less than half of the estimate of the current number of boats (approximately 3000) fishing the lake.

Estimation of MSY using age-based Thompson and Bell model

Mekkawy (1998) also calculated the yield, value of yield and biomass of *O. niloticus* and *S. galilaeus* using an age-based Thompson and Bell model (Sparre et al. 1992). No details of the intermediate parameters underlying this assessment are provided by Bishai et al. (2000).

Environmental considerations and effects

Water levels

It has been hypothesized that fish production in Lake Nasser is influenced by water level through its effect on spawning and feeding habitat availability (Habib et al. 2014; Figure 8). Variation in lake level in the preceding year explained approximately 50% of the variation in the annual recruitment of *O. niloticus* and *S. galilaeus* (Mekkawy 1998). Habib (2015) gives details of the linear regression models used to describe the recruitment variation.

Fishery or resource	Reference points	Estimates	Method	References	Comments
Multispecies assemblage	MSY	59,700 t	Schaefer model: Equilibrium fitting method; models fitted to individual *khors* before summing MSY estimates (Data: 1988–1994)	Mekkawy (1998)	Equilibrium assumptions. No account of lake-level fluctuations.
Multispecies assemblage	MSY	62,000 t	Schaefer model: Equilibrium fitting method; model fitted to observations for the whole lake (Years included: ?)	Mekkawy (1998)	Equilibrium assumptions. No account of lake-level fluctuations.
Multispecies assemblage	MSY; f_{MSY}	57,500 t; 1,313 boats	Schaefer model with additional area term (A): Equilibrium fitting method; model fitted to observations for the whole lake (Years included: ?)	Mekkawy (1998)	Equilibrium assumptions. Area term accounts for variation in spawning habitat area (recruitment) with lake area.
O. niloticus and *S. galilaeus*	MSY	54,000 t	Graham curve	Mekkawy (1998)	Equilibrium assumptions. No account of lake-level fluctuations.
Multispecies assemblage	MSY	58,000 t	Graham curve	Mekkawy (1998)	Equilibrium assumptions. No account of lake-level fluctuations. Assumes tilapiine species form 93% of total yield of lake assemblage.
O. niloticus and *S. galilaeus*	MSY; f_{MSY}	55,935 t; 9,037 boats	Schaefer model: Equilibrium fitting method	Mekkawy (1998)	Equilibrium assumptions. No account of lake-level fluctuations.
O. niloticus	MSY; f_{MSY}	32,342 t; 9,037 boats	Schaefer model: Equilibrium fitting method	Mekkawy (1998)	Equilibrium assumptions. No account of lake-level fluctuations.
S. galilaeus	MSY; f_{MSY}	23,592 t; 903 boats	Schaefer model: Equilibrium fitting method	Mekkawy (1998)	Equilibrium assumptions. No account of lake-level fluctuations.
Hydrocynus species	MSY; f_{MSY}	3,364 t; 2,636 boats	Schaefer model: Equilibrium fitting method	Mekkawy (1998)	Equilibrium assumptions. No account of lake-level fluctuations.
Lates niloticus	MSY; f_{MSY}	1,490 t; 1,061 boats	Schaefer model: Equilibrium fitting method	Mekkawy (1998)	Equilibrium assumptions. No account of lake-level fluctuations.
Labeo spp.	MSY; f_{MSY}	640 t; 988 boats	Schaefer model: Equilibrium fitting method	Mekkawy (1998)	Equilibrium assumptions. No account of lake-level fluctuations.
Bagrus spp.	MSY; f_{MSY}	109 t; 991 boats	Schaefer model: Equilibrium fitting method	Mekkawy (1998)	Equilibrium assumptions. No account of lake-level fluctuations.
Clarias spp.	MSY; f_{MSY}	107 t; 1,009 boats	Schaefer model: Equilibrium fitting method	Mekkawy (1998)	Equilibrium assumptions. No account of lake-level fluctuations.
O. niloticus	MSY	25,337 t	Generalized stock production model: Asymptotic	Mekkawy (1998)	No account of lake-level fluctuations.
O. niloticus	MSY	15,614 t	Generalized stock production model: Gompertz	Mekkawy (1998)	No account of lake-level fluctuations.
O. niloticus	MSY	15,348 t	Generalized stock production model: Logistic	Mekkawy (1998)	No account of lake-level fluctuations.
S. galilaeus	MSY	32,970 t	Generalized stock production model: Asymptotic	Mekkawy (1998)	No account of lake-level fluctuations.
S. galilaeus	MSY	16,543 t	Generalized stock production model: Gompertz	Mekkawy (1998)	No account of lake-level fluctuations.
S. galilaeus	MSY	13,658 t	Generalized stock production model: Logistic	Mekkawy (1998)	No account of lake-level fluctuations.
Multispecies assemblage	MSY	62,360 t	Generalized stock production model: Asymptotic	Mekkawy (1998)	No account of lake-level fluctuations. Assumes tilapiine species form 93% of total yield of lake assemblage.
O. niloticus	MSY	30,127 t	Thompson and Bell model	Mekkawy (1998)	Few details available to assess robustness of assessment.
S. galilaeus	MSY	17,692 t	Thompson and Bell model	Mekkawy (1998)	Few details available to assess robustness of assessment.

Table 14. Summary of estimates of target and limit reference points for Lake Nasser.

Van Zweiten et al. (2011) detected a significant effect of water level on tilapia production 2 years later, explaining about 20% of the variation in tilapia landings. However, these workers dismissed the earlier findings of Yamaguchi et al. (1996), who reported a significant multiple regression equation for prediction catch from the lake as a function of water levels in year y-1 and year y-3. (See Bishai et al. [2000], 389). No explanations were provided for why water levels in the year y-2 were not significant in determining yields.

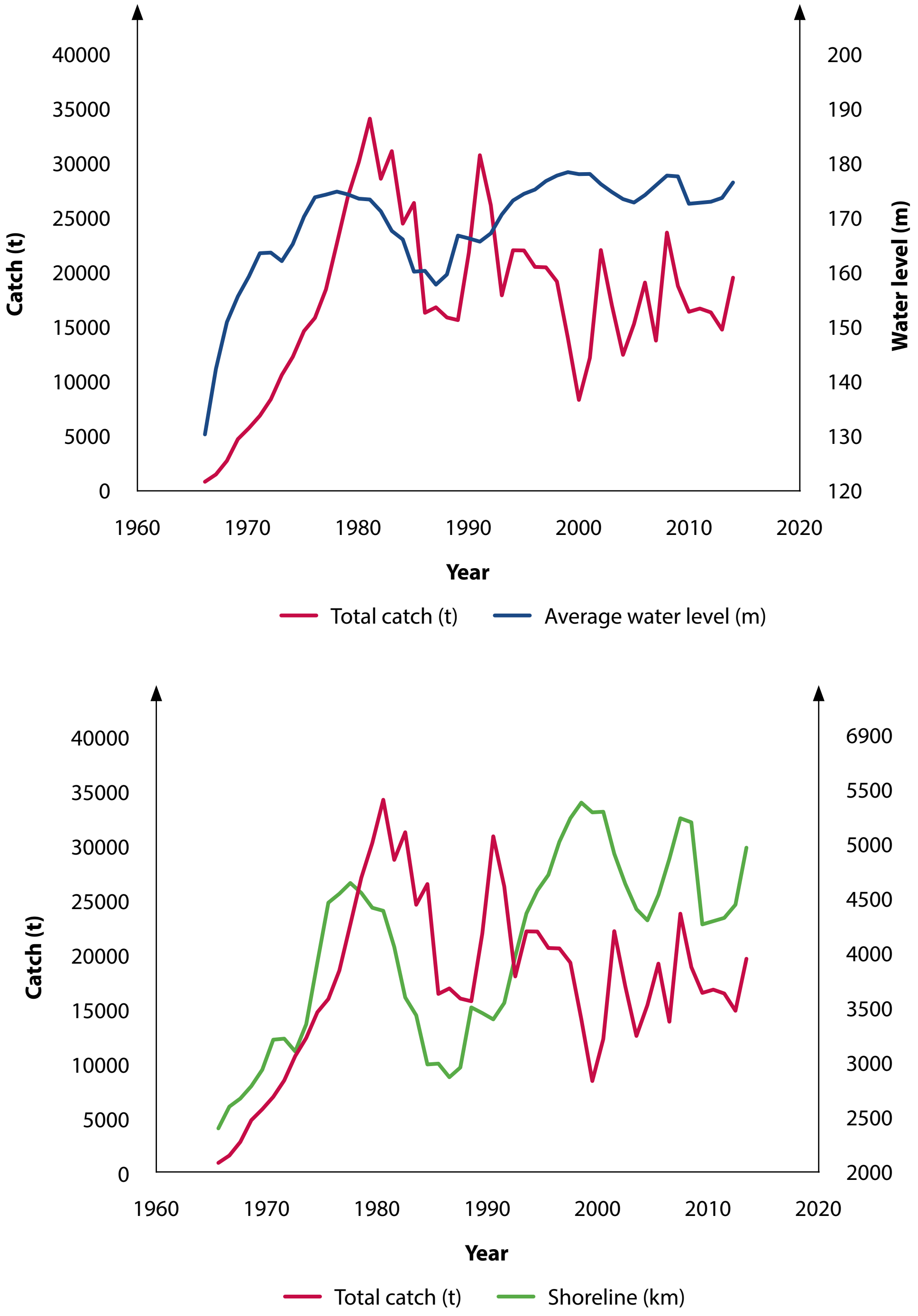


Figure 8. Time series of reported catch from Lake Nasser and water level and shoreline length estimated using the multiple linear regression model of Yamaguchi et al. (1996).

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ANNEX 1. CATCH, EFFORT AND WATER LEVEL ESTIMATES

Year	Fresh catch (t)	Salted catch (t)	Total catch (t)	Boats	Average water level (m)	Shoreline (km)
1964					116.37	1,302
1965					124.2	2,081
1966	347	404	751	200	130.17	2,390
1967	782	633	1,415	350	142.28	2,591
1968	1,152	1,510	2,662	500	150.92	2,666
1969	2,802	1,868	4,670	599	155.68	2,779
1970	3,370	2,306	5,676	816	159.34	2,932
1971	4,316	2,503	6,819	1,039	163.64	3,209
1972	5,303	3,040	8,343	1,135	163.76	3,218
1973	8,027	2,560	10,587	1,440	162.17	3,101
1974	8,030	4,225	12,255	1,540	165.32	3,352
1975	10,384	4,251	14,635	1,630	170.38	3,921
1976	10,979	4,862	15,841	1,680	173.98	4,472
1977	12,279	6,192	18,471	1,690	174.45	4,554
1978	17,852	4,873	22,725	1,700	175	4,653
1979	22,649	4,372	27,021	1,613	174.49	4,561
1980	26,344	3,872	30,216	1,570	173.7	4,425
1981	31,295	2,911	34,206	1,500	173.54	4,398
1982	25,979	2,688	28,667	1,450	171.4	4,064
1983	28,825	2,397	31,222	1,388	167.75	3,597
1984	22,069	2,465	24,534	1,385	166.19	3,434
1985	24,975	1,475	26,450	1,203	160.25	2,981
1986	15,023	1,292	16,315	1,379	160.37	2,987
1987	15,287	1,528	16,815	1,325	157.85	2,861
1988	14,579	1,309	15,888	1,349	159.72	2,952
1989	14,031	1,619	15,650	1,349	166.91	3,507
1990	20,129	1,753	21,882	1,915	166.38	3,453
1991	29,642	1,196	30,838	1,927	165.79	3,395
1992	24,721	1,498	26,219	1,956	167.29	3,547
1993	16,723	1,208	17,931	1,856	170.78	3,976
1994	20,491	1,583	22,074	2,524	173.39	4,373
1995	19,693	2,365	22,058	2,824	174.62	4,584
1996	18,159	2,381	20,540	2,834	175.41	4,729

Year	Fresh catch (t)	Salted catch (t)	Total catch (t)	Boats	Average water level (m)	Shoreline (km)
1997	16,546	3,957	20,503	2,792	176.96	5,034
1998	15,013	4,190	19,203	2,200	177.98	5,250
1999	9,876	4,107	13,983	2,200	178.63	5,394
2000	3,908	4,373	8,281		178.23	5,305
2001	7,556	4,608	12,164		178.26	5,311
2002	18,513	3,580	22,093	2,662	176.41	4,923
2003	12,734	4,295	17,029		174.96	4,646
2004	8,070	4,364	12,434		173.63	4,413
2005	11,015	4,270	15,285	2,880	173	4,309
2006	12,384	6,714	19,098	2,950	174.39	4,544
2007	7,918	5,838	13,756	2,927	176.18	4,877
2008	17,691	6,011	23,702	2,974	177.98	5,250
2009	14,620	4,170	18,790	3,030	177.81	5,213
2010	12,488	3,928	16,416		172.77	4,272
2011	13,167	3,533	16,700		172.95	4,301
2012	13,035	3,315	16,350		173.14	4,332
2013	11,219	3,548	14,767	3,046	173.87	4,453
2014	14,137	5,426	19,563		176.69	4,979

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